APPENDIX A

FLAT PANEL DISPLAY TECHNOLOGIES

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FLAT PANEL DISPLAY TECHNOLOGIES

1. Background

Flat panel displays (FPDs) are increasingly gaining a presence in the computer display market. They provide, for example, a more compact display as used in laptop computers and are viable substitutes for cathode ray tube (CRT) displays. Other advantages over the CRT are higher contrast, sunlight readable, more reliable, and more durable (i.e., require much less maintenance) Koch and Keoleian, 1995). In general, the major disadvantages have been that the resolution and quality of the image did not match that of CRTs. Several different types of FPD technologies have been demonstrated and are in use to varying degrees. The major categories are liquid crystal displays (LCD), plasma display panels (PDP), electroluminescent (EL), field emission displays (FED), vacuum fluorescent displays (VFD), digital micromirror devices (DMD), and light emitting diodes (LED). Table A-1 briefly describes each FPD technology. Although each technology has its own performance characteristics and is manufactured using different materials and processes, most are generally comprised of two glass plates surrounding a material that filters external light or emits its own light. These technologies use manufacturing techniques more similar to the production of semiconductor chips than televisions. Most FPDs control the color and brightness of each pixel (picture element) individually, rather than from one source, such as the electron gun in the CRT. The different types of electronic information display devices and how they are categorized are depicted in Fig. A-1.

1.1 Elimination of FPD Technologies from this Study

While there are several types of FPDs, two LCD technologies will be included in this LCA, based on their applicability to be used as substitutes in the computer display market. LCDs comprise approximately 87% of the FPD market (OTA, 1995). Currently, the largest market for FPDs is in notebook computers and CRTs monopolize the desktop computer market. However, FPDs are already moving into the desktop computer market. The LCD technology that best meets the purpose and needs of this study is the amorphous-silicon thin film-transitor (a:Si TFT) active matrix LCD (AMLCD). There are two variations of the a:Si TFT AMLCD that are expected to dominate the desktop monitor market for LCDs: the traditional twisted nematic (TN) mode and the in-plane switching (IPS) mode. Table A-1 describes these technologies. Various subtechnologies of LCDs are presented in Fig. A-2. The IPS mode is a non-nematic amorphous silicon AMLCD. Note that all the subtechnologies listed in Fig A-2 are not described here; the purpose is simply to show the complexity of different types of LCDs.

The PDP technology could be incorporated into the desktop computer market, especially if computers and televisions begin to merge. However, plasma technology is generally designed for large screens, and does not meet the specifications (e.g., diagonal size) of the functional unit defined for this project. Therefore, PDP technology will not be included in the scope of this project. FED and EL technologies are targeted toward military, medical, and high-end commercial products because they possess particular characteristics (such as size, durability, and high image quality) for those niche markets. Because these other FPD technologies are a small fraction of the market, not targeted toward the desktop computer market, and/or do not meet the specifications of our functional unit, they are not included within the scope of this project. Table A-1 presents brief descriptions of various FPD technologies and whether or not they are included in this LCA.

Table A-1. Flat panel display technologies

Technology	Description	Applicability to Project
Liquid Crystal Displays (LCD)	A liquid crystal material, acting like a shutter, blocks, dims, or passes light unobstructed, depending on the magnitude of the electric field across the material (OTA, 1995). A backlight provides the light source.	Included in this study. Descriptions of the subtechnologies and whether or not they are included in the study are presented below.
(1) Passive matrix (PMLCD)	Liquid crystal (LC) material is sandwiched between two glass plates, which contain parallel sets of transparent electrical lines (electrodes) in a row and column configuration to form a matrix. Every intersection forms a pixel, and the voltage across the pixel causes the LC molecules to align and determines the shade of that pixel (OTA, 1995).	Traditionally for low-end applications (e.g., calculators, wrist watches). Higher end applications use a super-twisted nematic (STN)[1] construction. The liquid crystal material is twisted between 180 and 270 degrees which improves the contrast between the "on" and "off" states, resulting in a clearer display than with the twisted nematic (twisted only 90 degrees) (OTA, 1995; MCC, 1997). However, cost and performance issues limit this technology from wide application in the desktop market and therefore, it will not be evaluated in this study.
(2) Active matrix (AMLCD)	Similar to the PMLCD except an electronic switch at every pixel provides faster switching and more shades. The addressing mechanism eliminates the viewing angle and brightness problems suffered by PMLCD. Requires more backlight than PMLCD due to the additional switching devices on the glass (at each pixel). Various switching types are listed below:	Provides vivid color graphics in portable computer and television screens (OTA, 1995). This technology meets the functional unit specifications in this study. Specific subcategories are described below.

[1] Traditional light modulating methods for LCD technologies include twisted nematic (TN), super-twisted nematic (STN), double STN, triple STN, and film-compensated STN (OTA, 1995). The STN is the current standard for high-end PMLCD applications.

Table A-1. Flat panel display technologies

Technology	Description	Applicability to Project
	AMLCD Switch Types:	
	(2a) Thin-film transistor (TFT): The transistor acts as a valve allowing current to flow to the pixel when a signal is applied. The transistors are made of various materials including: amorphous silicon (a:Si), polycrystalline silicon (p:Si), non-Si[CdSe] (Castellano, 1992). Two different TFT light modulating modes are twisted nematic (TN) and in-plane switching (IPS) (DisplaySearch 1998). In comparison to the TN mode, the IPS mode requires more backlight but fewer manufacturing steps.	The current standard AMLCD switching mechanism for computer displays is a:Si TFT. Polycrystalline Si is not suitable for larger than about 5" displays. Both the TN and IPS a:Si TFT AMLCD technologies are analyzed in this project.
	(2b) Diode matrix: The diode acts as a check valve. When closed, it allows current to flow to the pixel charging it. When opened, the pixel is disconnected and the charge is maintained until the next frame (Castellano, 1992).	The diodes are found to short easily and must be connected in series to achieve long life usability. The diode displays are also limited in size smaller than that of the functional unit.
	(2c) Metal-insulator metal (MIM): The MIM is a diode type switch using metal-insulated-metal fabrication techniques (OTA, 1995).	Temperature sensitive, which creates gray scale nonuniformities. They are also size limited like other diode type displays and therefore not included in this study.
(3) Active addressed LCD	Hybrid of passive and active matrix. The pixels are addressed using signals sent to the column and row as determined using an algorithm encoded into an integrated circuit (IC). The IC drives each row of pixels more or less continuously and drives multiple rows at one time (OTA, 1995)	Employed in notebook and desktop monitors >12.1". However, they need special drivers (OTA, 1995), have slow response times, and their contrast worsens as panel size increases (Young, 1998). Therefore, this technology does not meet the specifications of the functional unit and is excluded from evaluation in this study.
(4) Plasma-addressed liquid crystal (PALC)	The pixel is addressed using row electrodes, which send the signal, and column gas channels, which conduct a current when ionized (OTA, 1995).	PALC displays are in development to be used as large low cost displays. Production of the displays have not yet occurred and they are not included in this study.
(5) Ferroelectric LCDs (FLCD or FELCD)	The pixel is addressed using positive or negatives pulses to orient the crystals. The positive pulse allows light to pass (light state) and the negative pulse causes the blockage of light (dark state) (Castellano, 1992). A ferroelectric liquid crystal is bistable and holds it polarization when an electric field is applied and removed (Peddie, 1994). They are also called surface stabilized ferroelectric (SSF) LCD.	Has high resolution with very good brightness, but limited color palette (Peddie, 1994). Limited color palette does not meet color specification of functional unit.

Table A-1. Flat panel display technologies

Technology	Description	Applicability to Project
Plasma Display Panels (PDP)	An inert gas (e.g., He, Ne, Ar) trapped between the glass plates emits light when an electric current is passed through the matrix of lines on the glass. Glow discharge occurs when ionized gas undergoes recombination. Ionization of atoms occurs (electrons are removed), then electrons are recombined to release energy in the form of light. Full color plasma displays use phosphors that glow when illuminated by the gas (OTA, 1995).	Established technology. Good for large screens (e.g., wall-mounted televisions), but are heavier and require more power than LCDs (OTA, 1995). Designed for large screens and are larger displays than specified for desktop applications. Therefore, not included in this study.
Electroluminescent Displays (EL)	A phosphor film between glass plates emits light when an electric field is created across the film (OTA, 1995). EL uses a polycrystalline phosphor (similar to LED technology which is also an electroluminescent emitter, but uses a single crystal semi-conductor). ELs are doped (as a semiconductor) with specific impurities to provide energy states that lie slightly below those of mobile electrons and slightly above those of electrons bound to atoms. Impurity states are used to provide initial and final states in emitting transitions (Peddie, 1994). Also referred to as thin-film EL (TFEL). Variations: AC thin-film EL (AC-TFEL), active matrix EL (AMEL), DC EL, organic EL.	Lightweight and durable. Used in emergency rooms, on factory floors, and in commercial transportation vehicles (OTA, 1995). Problems found in the power consumption and controlling of gray levels. Targeted toward military, medical, and high-end commercial products, therefore not included in the scope of this project.
Field Emission Displays (FED)	Flat CRT with hundreds of cathodes (emitters) per pixel (form of cathodeluminescent display); eliminates single scanning electron beam of the CRT. Uses a flat cold (i.e., room temperature) cathode to emit electrons. Electrons are emitted from one side of the display and energize colored phosphors on the other side (OTA, 1995; Peddie, 1994).	Not commercially available, but anticipated to fill many display needs (OTA, 1995). Could potentially apply in all LCD and CRT applications. High image quality as with CRT, but less bulky and less power use than with CRT. A number of roadblocks to this technology taking over the AMLCD market include proven manufacturing processes (problems found in the reliability and reproducibility of the devices), efficient low-voltage phosphors, and high voltage drivers. The technology is targeted toward military, medical and high-end commercial products and not included in current study.
Vacuum Fluorescent Displays (VFD)	Form of cathodeluminescent display that employs a flat vacuum tube, a filament wire, a control grid structure, and a phosphor-coated anode. Can operate at low voltages since very thin layers of highly efficient phosphors are coated directly onto each transparent anode (Peddie, 1994).	VFDs offer high brightness, wide viewing angle, multi-color capability and mechanical reliability. Used in low information content applications (e.g., VCRs, microwaves, audio equipment, automobile instrument panels, etc.). No significant uses seen for computer displays (Peddie, 1994).

Table A-1. Flat panel display technologies

Technology	Description	Applicability to Project
Digital Micromirror Devices (DMD)	Miniature array of tiny mirrors built on a semiconductor chip. The DMD is used in a projector that shines light on the mirror array. Depending on the position of a given mirror, that pixel in the display reflects light either onto a lens that projects it onto a screen (resulting in a light pixel) or away from the lens (resulting in a dark pixel) (OTA, 1995).	Just beginning to be used mainly as projection devices and has not been developed for use that would match the functional unit (OTA, 1995).
Light Emitting Diodes (LED)	The LED device is essentially a semiconductor diode, emitting light when a forward bias voltage is applied to a p-n junction. The light intensity is proportional to the bias current and the color dependent on the material used. The p-n junction is formed in a III-V group material, such as aluminum, gallium, indium, phosphorous, antimony, or arsenic.	For low information display applications, which makes it not capable of meeting the requirements of the functional unit. Color, power, and cost limitations prevent the emergence into the high information display market (Castellano, 1992).
Electrochromic display	Open-circuit memory using liquid electrolytes (Peddie, 1994, p. 214). Non-emitter (as LCDs), as opposed to emitters (e.g., EL, FED, PDP).	Outstanding contrast and normal and wide viewing angles; open-circuit memory. Complex and costly involving liquid electrolytes, poor resolution, poor cycle life, lack of multicolor capability, etc. Not suitable for computer displays in past; however, new technology may be promising (Peddie, 1994).
Light Emitting Polymers	Developing technology (Holton, 1997).	Developing technology.

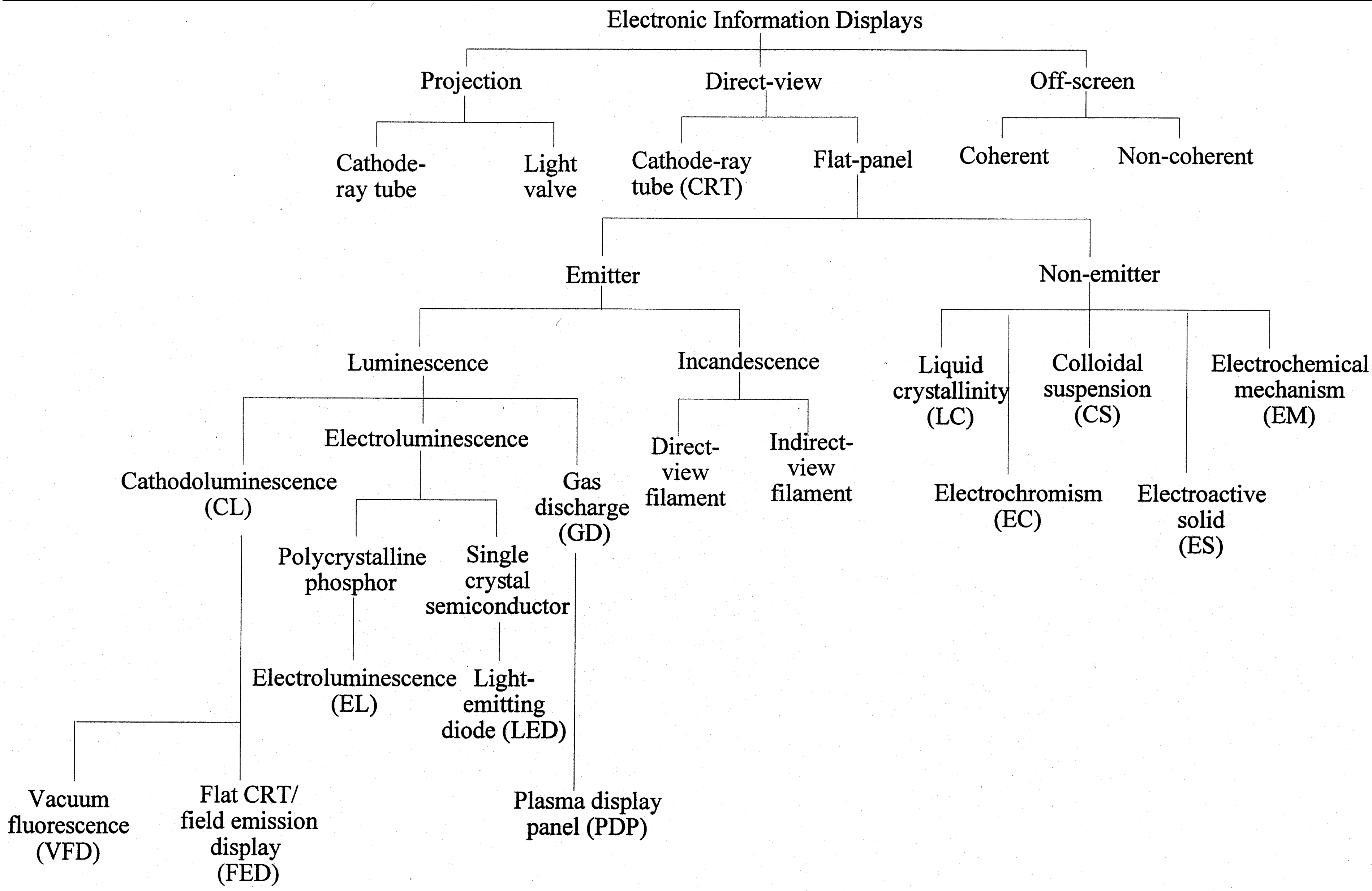

Figure A-1. Classification of Electronic Information Displays. ***Source:*** **Adapted from Tannas 1985.**

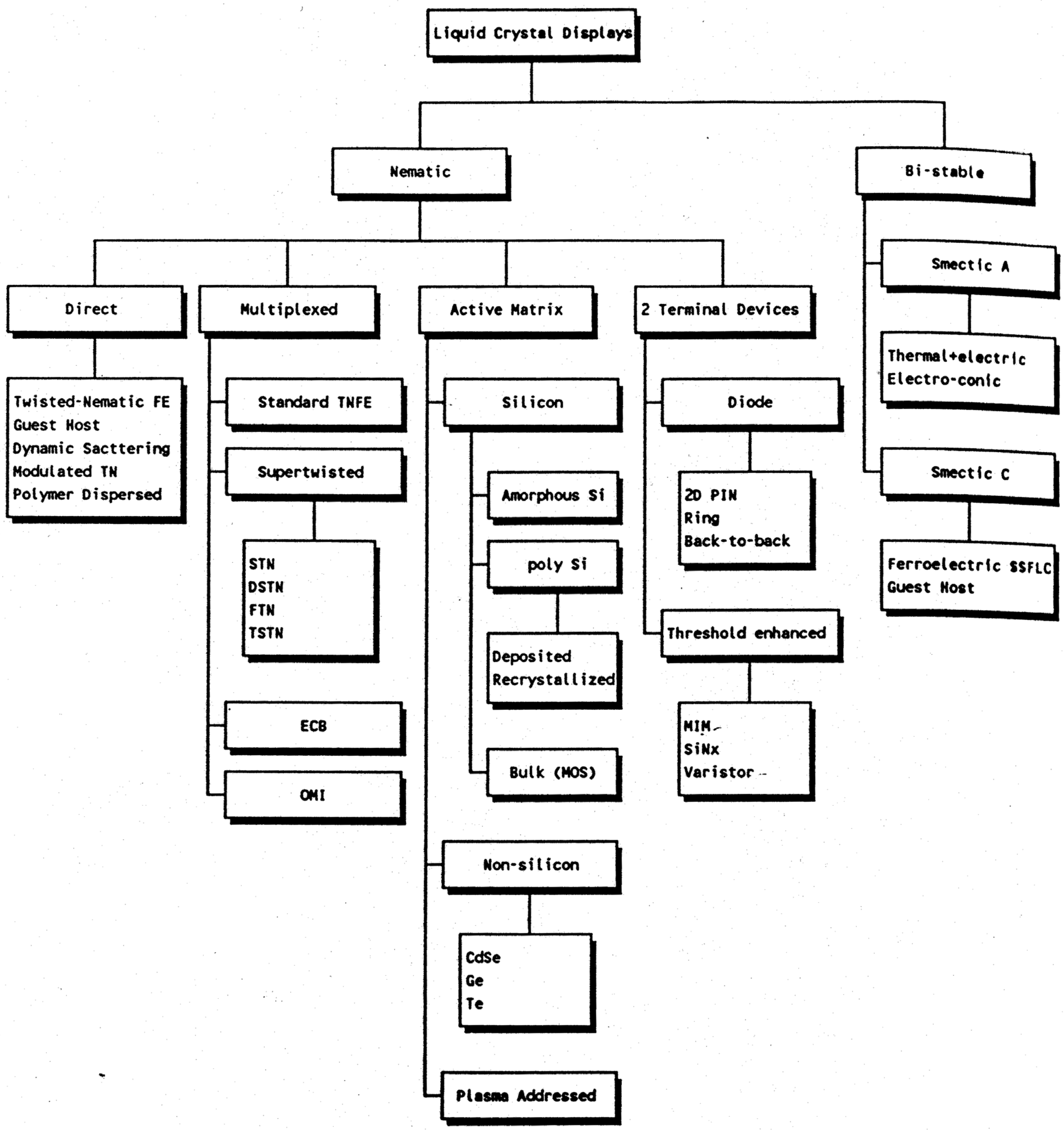

Figure A-2. LCD subtechnologies. Source: Catellano 1992.

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